712CD

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Simulating the Commander's Decision Process

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PRESENTED IN:

WORKING GROUP:	WG-6	**DEMONSTRATION:**	
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SPECIAL SESSION 1:		**TUTORIAL:**	
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Report Documentation Page	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
01 JUN 2007	**N/A**	**-**

4. TITLE AND SUBTITLE **Simulating the Commander’s Decision Process**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **The John Hopkins University Applied Physics Laboratory**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES

See also ADM202526. Military Operations Research Society Symposium (75th) Held in Annapolis, Maryland on June 12-14, 2007, The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**UU**	**33**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

75th MORSS CD Cover Page

For office use only 41205

UNCLASSIFIED DISCLOSURE FORM CD Presentation

12-14 June 2007, at US Naval Academy, Annapolis, MD

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Presented in: **WG-6**

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Simulating the Commander's Decision Process

13 June 2007

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Outline

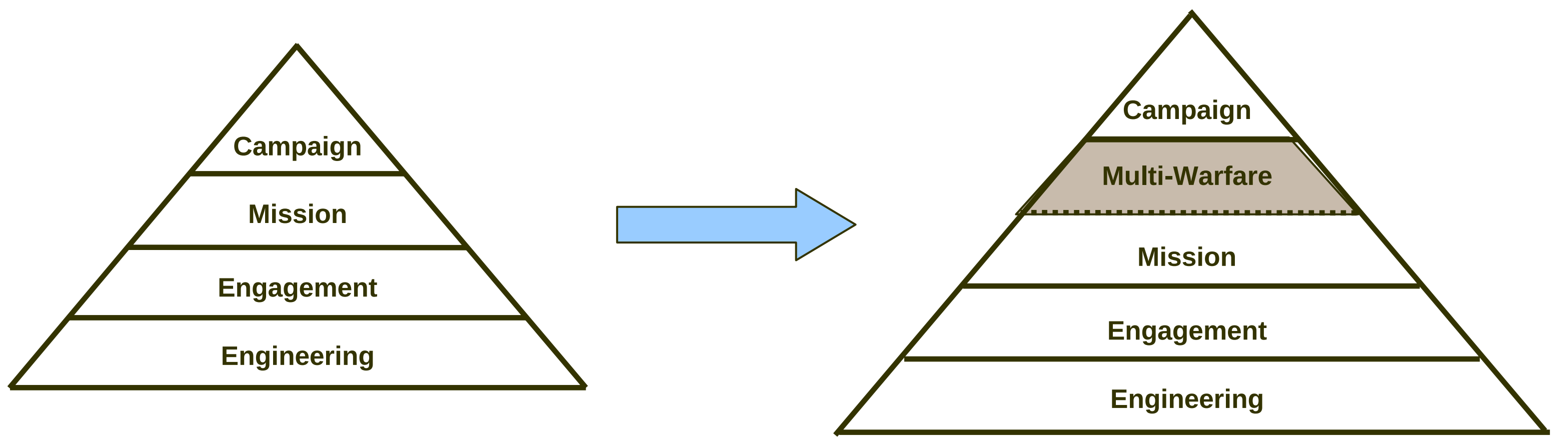
- Background
  - Previous analysis
  - Why multi-warfare
  - AIMS objectives
- AIMS Federation
  - Architecture
  - Command mapping
- Commander Federate Details
  - Responsibilities
  - Technologies
- Decision Process
  - Agent structure
  - Example scenario
  - Algorithm summaries
- Summary

Background: Previous Analysis

- Complexity of multi-warfare analysis has led to:
  - Abstraction upward to campaign-level simulations in which there is:
    - A reduction in the ability to properly account for the interactions in multi-warfare situations
    - A reduction in the ability to simulate operational and tactical details
  - Artificially stove-piped analyses in which:
    - The best models are used independently for each warfare area with the following limitations:
      - No single model can replace specialized mission-level simulations
      - Outputs of one model are fed as inputs to the next
      - Difficult to "integrate" results
      - Difficult to address inter-warfare area resource conflicts
      - Difficult to simulate appropriate responses to emerging events
    - The process is lengthy and manpower-intensive

Background: Why multi-warfare analysis?

- The defense community shows growing interest in multi-warfare analysis for:
  - Capabilities-based acquisition
  - Multi-mission structures (e.g., Sea Shield)
  - Assessment of multi-mission platforms (e.g., DDG1000)
  - Competition for multiple-missions capable assets (e.g., helicopters, for ASW and SUW)

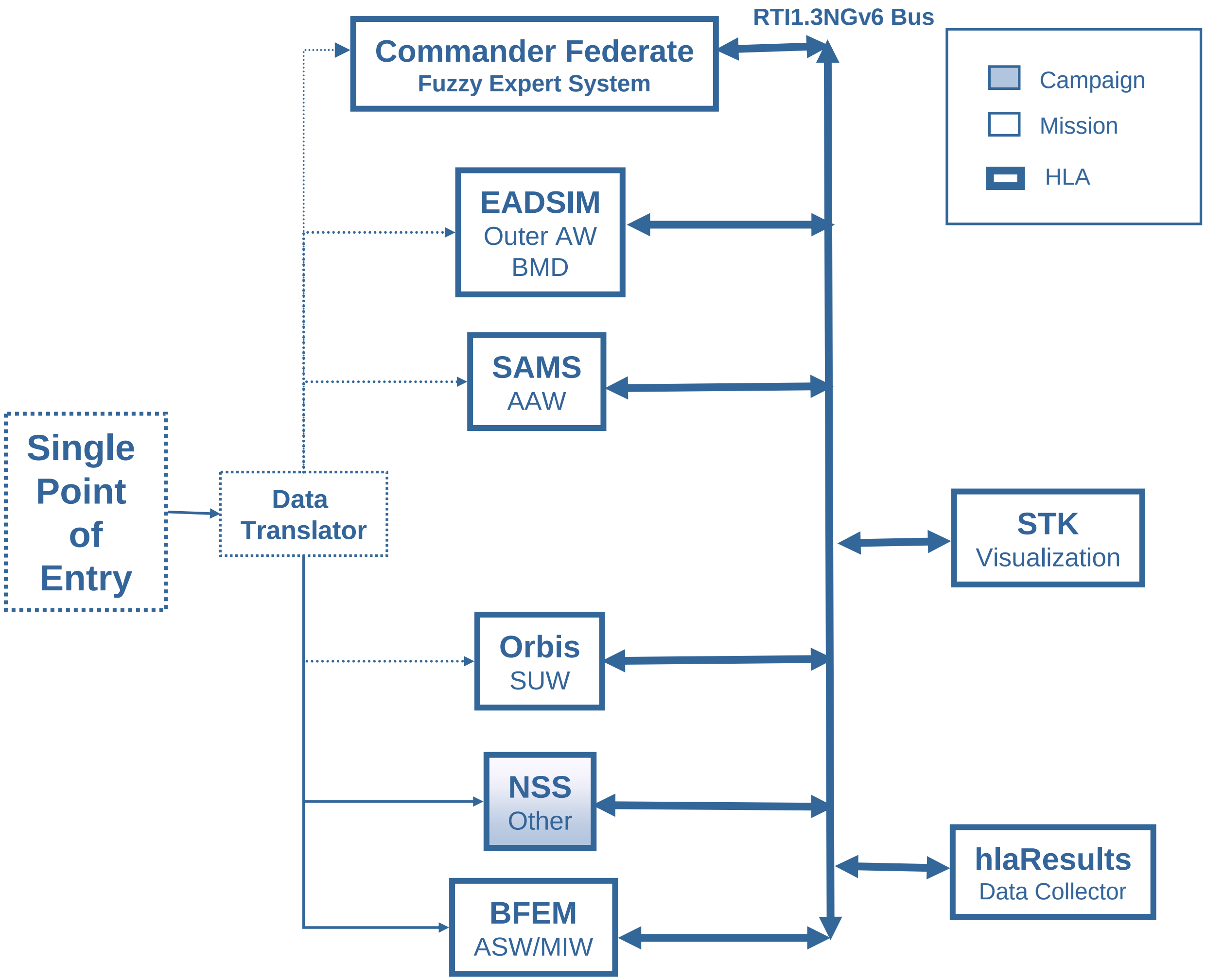


Background: Project Objectives

- APL Integrated Multi-warfare Simulation (AIMS)
  - Incorporate simulations of choice based on the analysis task
  - Incorporate reasoning technologies into a Commander federate to
    - Consider the effects of competing resources across multi-warfare areas and the warfare area dependencies
    - Simulate a Commander's proactive planning
  - Provide a Single Point of Entry (SPE) for scenario data
  - Coordinate execution of scenario runs and data collection
  - Visualize the scenario interactions
  - Assist in post-run analysis

AIMS Federation Architecture

- Simulations tied together with HLA RunTime Infrastructure (RTI) 1.3 Next Generation version 6.0
- Existing HLA compliant tools used (e.g., results collection: hlaResults)
- Simulations executed on Windows desktop systems



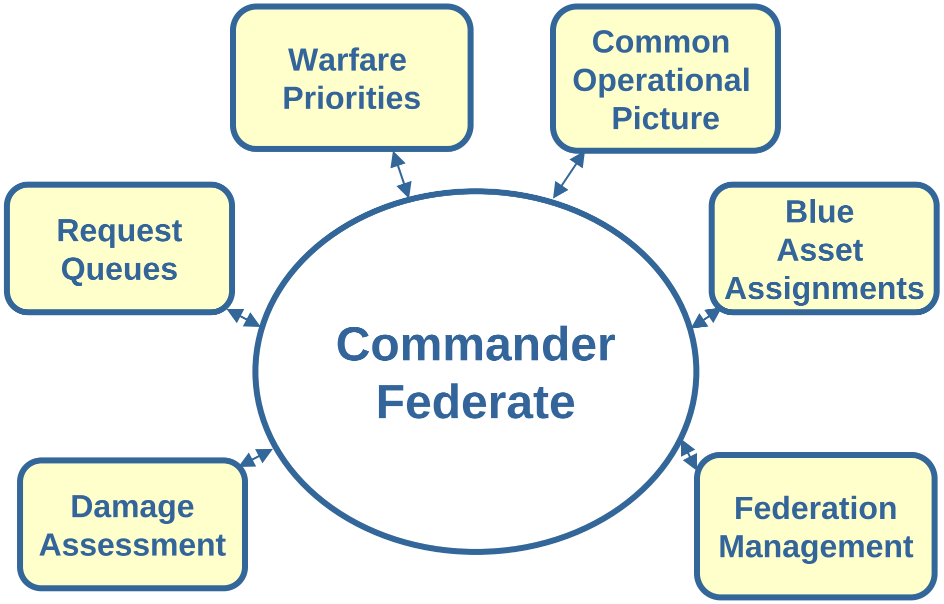
AIMS Federation Command Mapping

	Maritime Component Commander / Commander Federate					
Component Commanders	USWC	MIWC	SUWC	ADC		Other
Alignment w/Simulations in Federation	USWC / BFEM	MIWC / BFEM	SUWC / ORBIS	ADC / SAMS For AAW	ADC / EADSIM For BMD	Other / NSS
Platform Commanders	Platform A CDR *	Platform B CDR *	Platform C CDR *	Platform D CDR *	Platform E CDR *	Platform F CDR * …

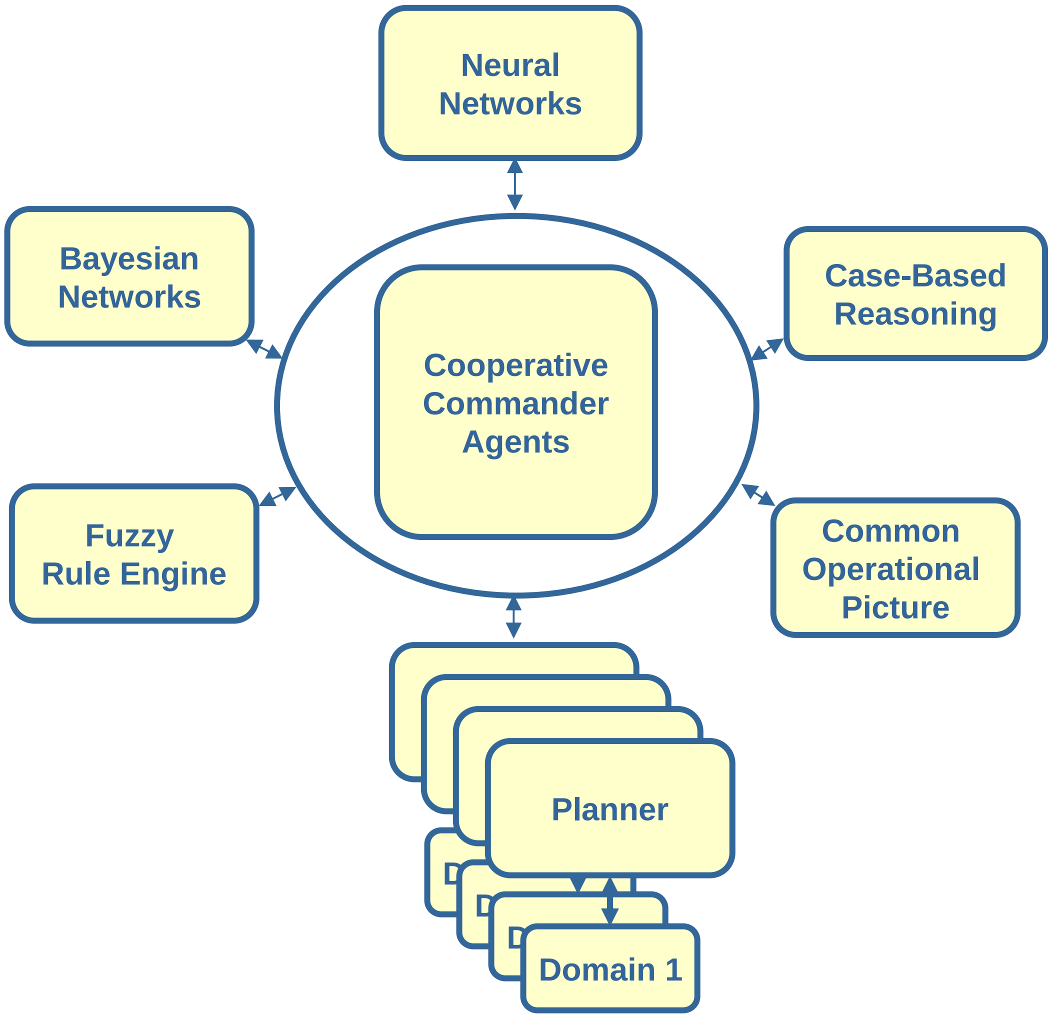
*Simulation in federation that is "controlling" a particular platform will change, e.g., as mission priorities change due to events; this is accomplished by "transfer of ownership" from one simulation to another

Commander Federate Responsibilities

- Performs basic federation management
- Manages warfare priorities
- Performs inter-warfare area conflict resolution for asset allocation
- Directs transfer of ownership of assets between simulations
- Conducts proactive planning based on observed events



Commander Federate reasoning technologies

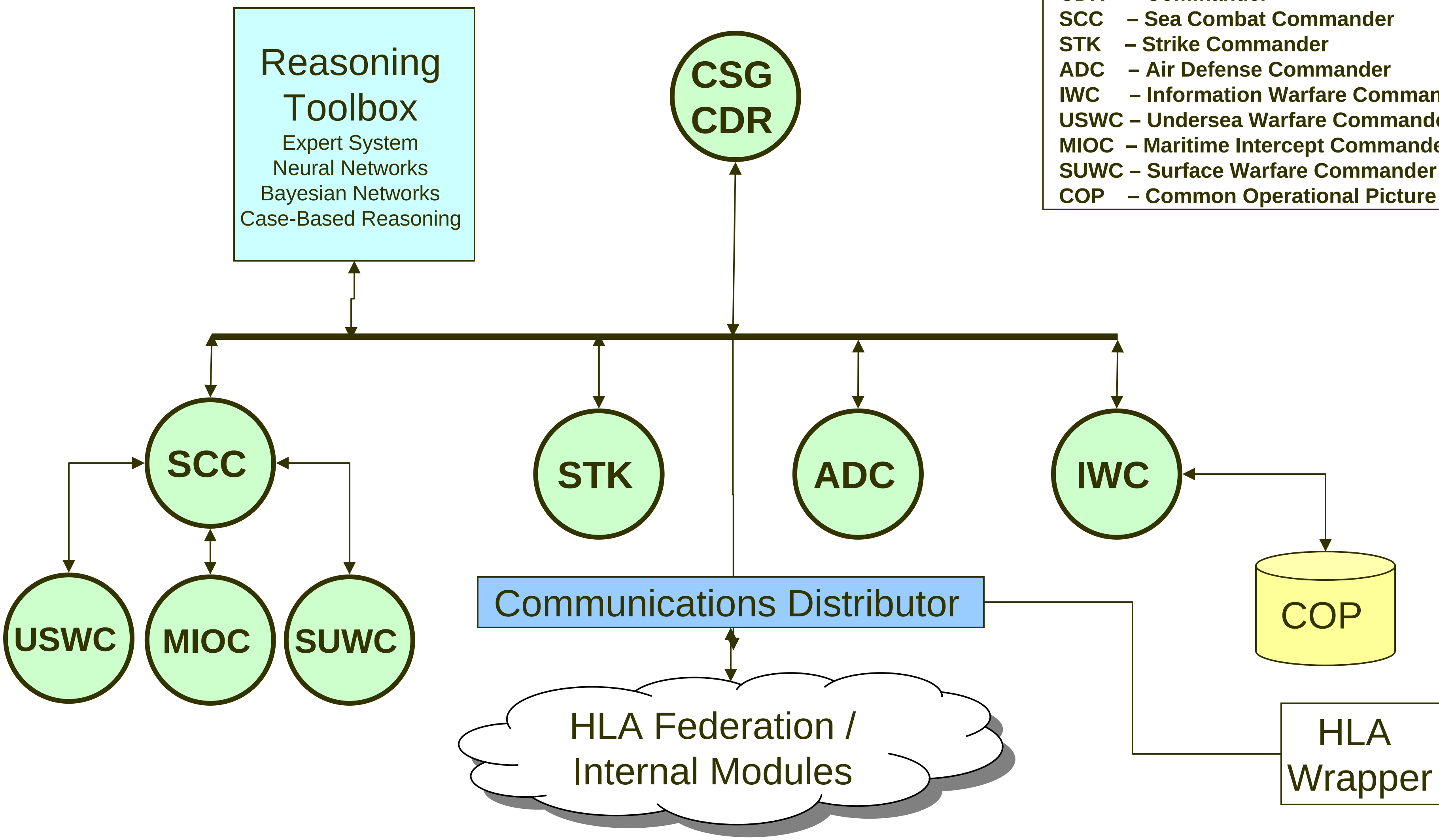


M&S Process

- Create a domain specific file using reasoning software GUI editor
- Export domain specific file
- Agents load specific files as needed for their function, provide problem specific inputs, and use the generic engine to create solution outputs

Commander Decision Making Structure

(*Within the Carrier Strike Group - CSG)*



CDR	**– Commander**
SCC	**– Sea Combat Commander**
STK	**– Strike Commander**
ADC	**– Air Defense Commander**
IWC	**– Information Warfare Commander**
USWC	**– Undersea Warfare Commander**
MIOC	**– Maritime Intercept Commander**
SUWC	**– Surface Warfare Commander**
COP	**– Common Operational Picture**

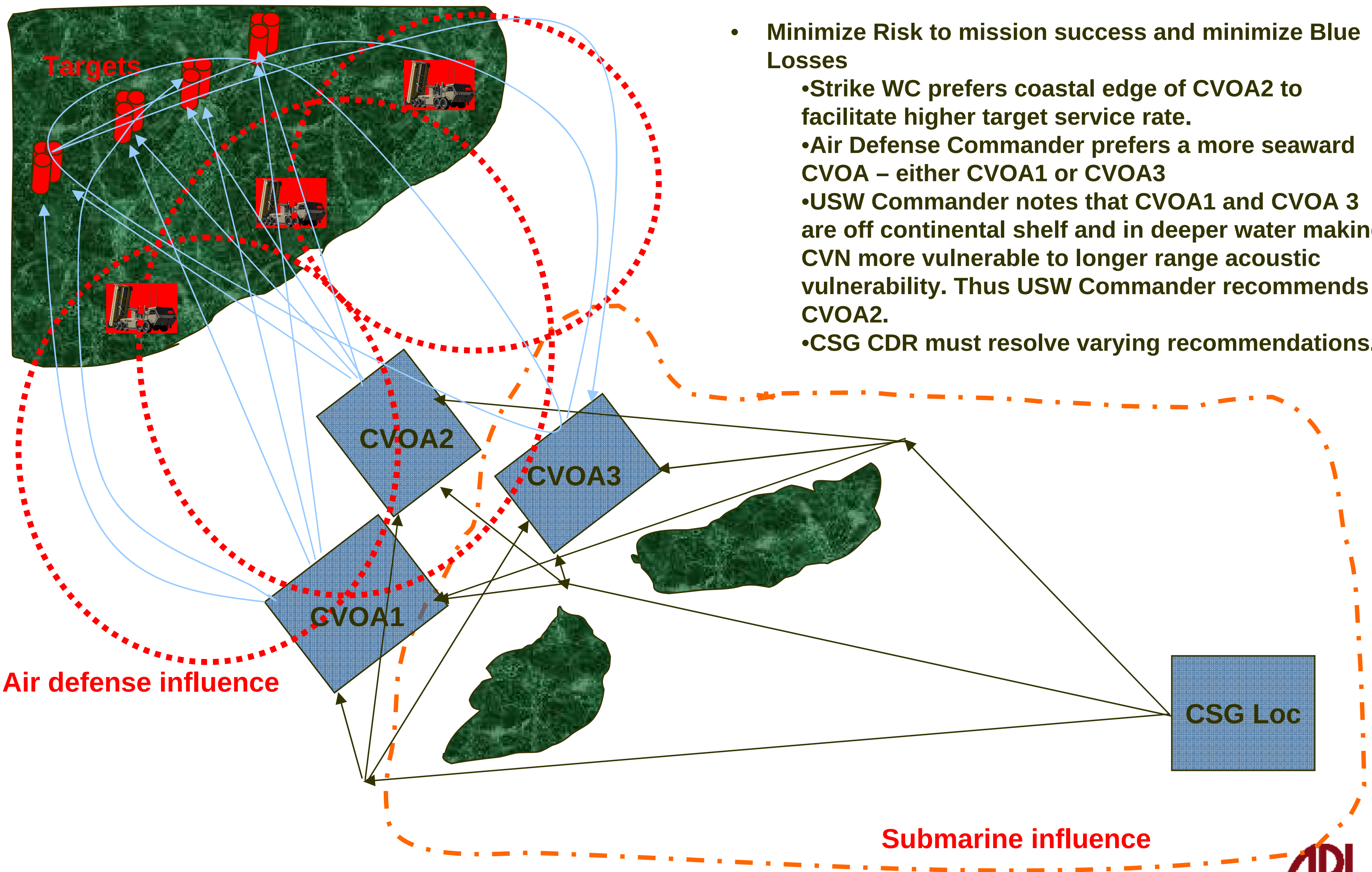
Note: CSG Warfare Commander's and structure are nominal and illustrative example only. It is realized that CSG organizations can vary.

Agent Roles

- <u>Carrier Strike Group (CSG) Commander</u>
  - Readiness
  - Overall Mission planning and execution
    - Asset allocation
    - Movement and stationing of the force
  - Rules of Engagement determination
  - Warfare priority setting
  - Defense of the force
    - Warning and weapons status

- <u>Each Warfare Commander</u>
  - Within assigned mission
    - Readiness
    - Assigned mission planning and execution
      - Asset requirements
      - Asset movement and stationing
    - Defense of assigned units
      - Warning and weapons status
  - Cross-mission cooperation
    - Multi-warfare mission planning and execution
      - Movement and stationing of the force
      - Asset priorities
    - Defense of the force
      - Warning and weapons status

Example Problem

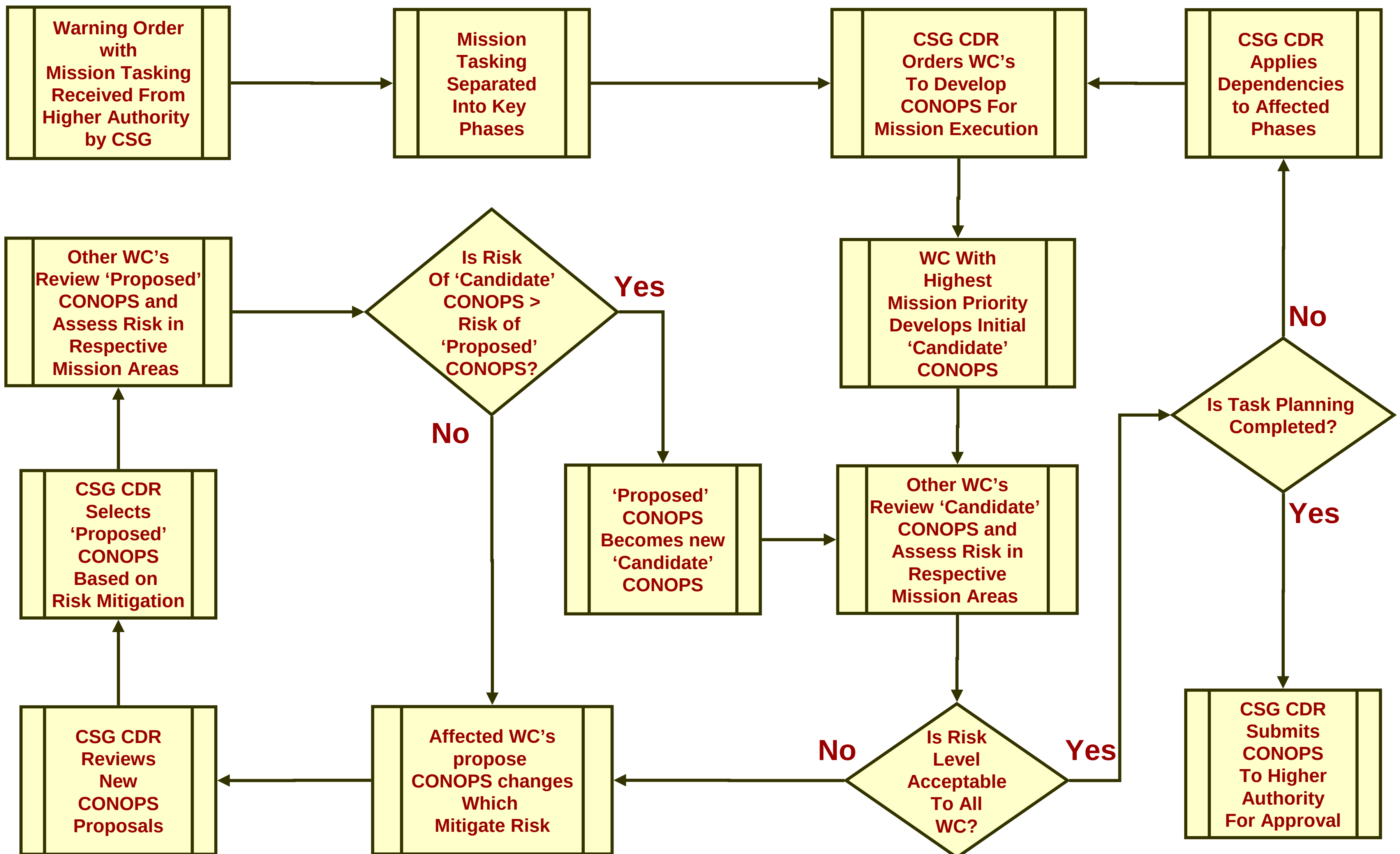


- **Minimize Risk to mission success and minimize Blue Losses**
  - **•Strike WC prefers coastal edge of CVOA2 to facilitate higher target service rate.**
  - **•Air Defense Commander prefers a more seaward CVOA – either CVOA1 or CVOA3**
  - **•USW Commander notes that CVOA1 and CVOA 3 are off continental shelf and in deeper water making CVN more vulnerable to longer range acoustic vulnerability. Thus USW Commander recommends CVOA2.**
  - **•CSG CDR must resolve varying recommendations.**

Main Decision Algorithm: Agent Interactions

1. CSG Commander (Commander Module) receives tasking message from higher authority.
2. CSG Commander breaks tasking into phases
3. For each phase
   a. CSG Commander orders subordinate warfare commanders to develop a CONOPs
   b. The warfare commander (WC) with the highest warfare priority submits a "candidate " CONOP to all other WC
   c. Repeat until no further mitigations are submitted or minimum success rates are achieved for each mission area
      1. Other WC respond to the current "candidate " CONOP with the risk assessment on their warfare area and a "mitigation" CONOP to lower its risk if necessary.
      2. CSG Commander then chooses a new "proposed" CONOP from among the "mitigation" CONOPs and asks the WCs for a risk assessment
      3. WC send risk assessments to the CSG Commander
      4. CSG Commander then chooses a new "candidate " CONOP if it results in less risk than the previous "candidate "

Agent Interaction Flowchart



Tasking Message Details

- Tasking messages provide the following information to the CSG Commander
  - Time Ordered List of missions
    - Targets and their respective value
    - List of candidate CVOAs
    - Start/end time
  - Start/end locations
  - Start/end times

Decompose Tasking Message into Phases

- If a transit is necessary, a separate transit phase is identified
- For each mission in tasking message
  - If location after previous phase is not within the CVOA for the next mission, CSG Commander creates a transit phase to CVOA for next mission
  - Then creates a mission execution phase

Order Candidate CONOPs Generation

- CSG Commander orders that a CONOP be constructed for the phase currently being planned
- The following phase information is provided to the Warfare Commanders
  - Targets and respective weights
  - Inter-phase dependencies
  - Probability of each asset surviving the previous phases (execution order)
  - Mission weights for each WC
  - WC risk thresholds

Construct Candidate CONOPs

- WC analyzes combinations of routes that are valid for the provided CVOAs, Inter-phase dependencies, asset assignments, and threats
  - Start with current asset assignments and daylight environment
  - Search for a CONOP that satisfies the risk tolerance threshold
    - Selected Motion* Plan
    - Time of start
    - Time of end (decided by time of start and motion plan)
    - Blue asset allocation to Warfare Areas / Formation

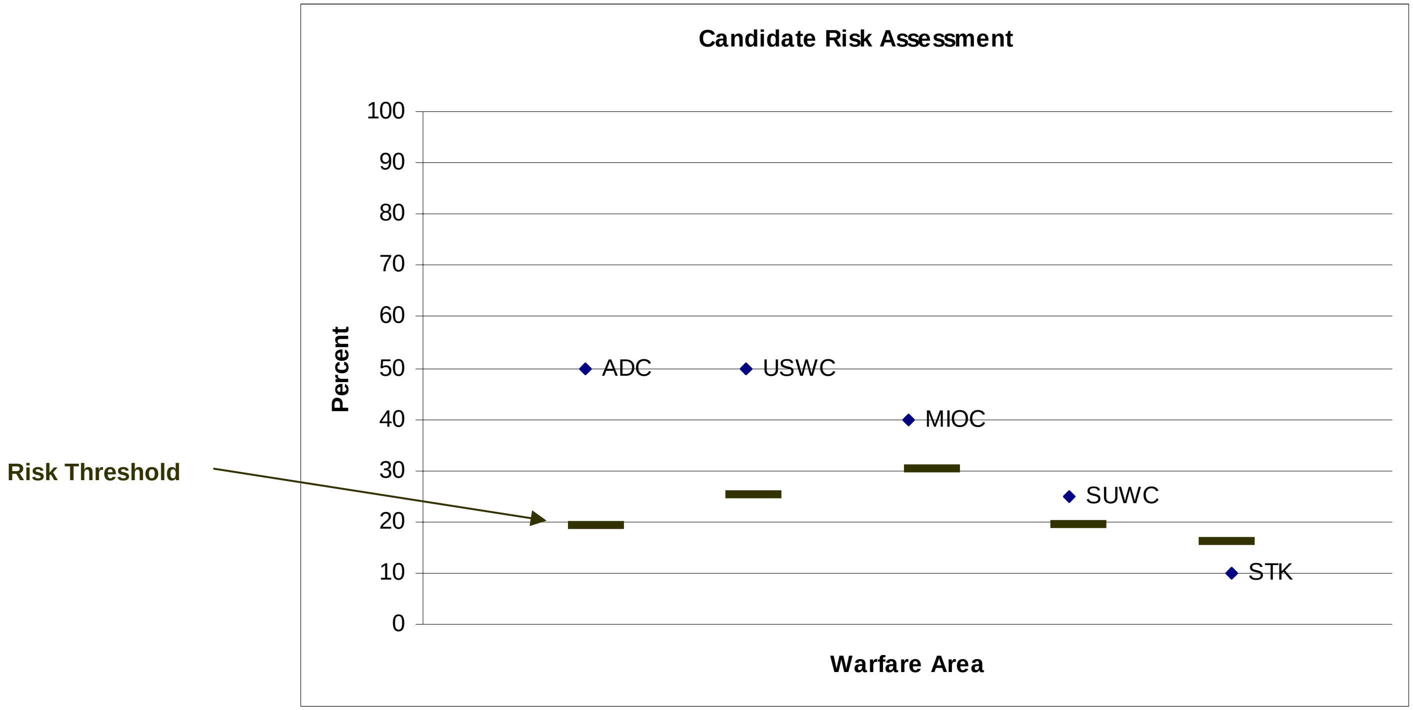
* Depending on operational situation, motion could alternatively refer to PIM, patrol, sector, grid, or formation but is used to convey location, direction and speed of each asset.

Assess Candidate CONOP Risks and Propose Alternatives

- Each WC assesses candidate CONOPs and calculates asset and mission risk affecting his mission area
- If risks unacceptable, each WC proposes mitigating CONOPs that reduces risks for his warfare area by varying:
  - Motion plan
  - Time of start
  - Asset ownership assignments / Formation
- Each WC uses a steepest decent algorithm to choose his proposed mitigation CONOP

Select an Alternative CONOPs for Comparison to Candidate

- The CSG Commander, considering all alternative WC CONOPs, selects the CONOPs developed by the WC whose assets and mission risk are the most above his minimum acceptable risk for the candidate CONOPs.
    - First CONOPs consideration is the WC who has determined that the CSG is at most risk to threats from his mission area if the candidate CONOPs is executed.
- Tie breaking algorithms consider the alternative that generated the largest decrease in WC calculated risk and warfare priority



Calculate Risk for Proposed CONOPs

- **CSG Commander broadcasts the selected alternative CONOPs as the newly proposed CONOPs**
- **WC's perform risk calculations for proposed CONOP and returns asset and mission risk to CSG Commander**

Determine Candidate CONOP

- **CSG Commander calculates total risk to the proposed CONOP and compares it to the Candidate**
  - **If Risk(Proposed CONOP) > Risk(Candidate CONOP)**
    - **The Candidate remains**
  - **If Risk(Proposed CONOP) < Risk(Candidate CONOP)**
    - **The Proposed CONOP becomes the new Candidate**
  - **CSG Commander distributes the Candidate and queries for mitigations**
- **The above repeats until no further mitigations are submitted or threshold risk levels are achieved for each mission area**

AIMS Value Added to Warfare Analysis

- Eliminates sequential, time-consuming data transfers between "stove-piped" single-warfare analysis simulations when conducting multi-warfare studies
- Enhances integrated warfare analysis through selective use of appropriate simulations which have been used in individual warfare area analyses
- Incorporates reasoning technologies into a Commander federate to
  - Consider the effects of competing resources across multi-warfare areas and the warfare area dependencies
  - Simulate a Commander's decision processes
- Focuses several warfare areas to a common scenario selection across all warfare areas
- Preserves the ability for each model to be used in a stand-alone mode
- Streamlines development of three-dimensional visualization of common OPSITs/TACSITs
- Single Point of Entry reduces duplication of effort and data entry errors by using a single interface for scenario creation

Summary

- APL Integrated Multi-warfare Simulation (AIMS) provides a flexible architecture to conduct analysis on the execution of integrated warfare in multiple mission areas

- Commander Federate simulates the human decision process by employing
  - A fuzzy expert system to set warfare priorities either by time or event and provides inter-warfare area conflict resolution for asset allocation
  - Simulates human decision processes through cooperative agents using a framework of reasoning technologies either in integrated or stand-alone warfare analysis

Backup Slides

WC Risk Calc

$$\mathbf{WCRisk(CONOPs)} = \mathbf{lossWeight}_{\mathbf{WC}} * \mathbf{lossRisk(CONOPs)} + \mathbf{missionWeight}_{\mathbf{WC}} * \mathbf{missionRisk(CONOPS)}$$

$$\mathbf{lossWeight}_{\mathbf{WC}} + \mathbf{missonWeight}_{\mathbf{WC}} = \mathbf{1.0}$$

Loss Risk (for one phase)

$$\text{lossRisk(CONOPs)} = \sum_{\text{blueAssets}} (\text{assetWeights[blueAsset]} * \text{pLoss(blueAsset, CONOPs)})$$

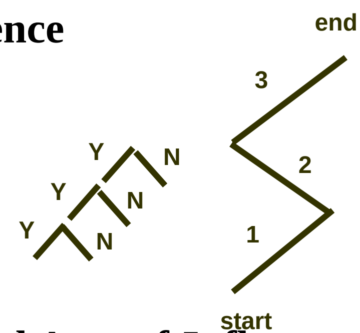
$$\text{blueAssets} = \{\text{blueAssets} \mid \text{pAlive(asset)} \geq \text{threshold}\}$$

$$\sum_{\text{blueAssets}} (\text{assetWeights[blueAsset]}) = 1.0$$

$$\text{pAlive(dp)} \equiv \text{probability delivery platform (dp) is alive after previous phase in execution order}$$

$$\text{pLoss(asset, CONOPs)} = \text{pLossAfter(asset, lastSegment)}$$

$$\begin{aligned} &\text{pLossAfter(asset segment)} \\ &\quad = \text{pLossDuring(asset, segment)} && \text{if segment is first in sequence} \\ &\quad = \text{pLossDuring(asset, segment)} \\ &\qquad * (1 - \text{pLossAfter(asset, segment - 1)}) \\ &\qquad + \text{pLossAfter(asset, segment - 1)} && \text{otherwise} \end{aligned}$$



where

$$\text{pLossDuring(asset, segment)} = \forall \text{ red } dp_1 \ldots dp_k \text{ with blue asset in their red Area of Influence}$$

$$P(\text{ pAlive}(dp_1) * \text{pk}(dp_1, \text{asset, segment}) \vee \ldots \vee \text{pAlive}(dp_k) * \text{pk}(dp_k, \text{asset, segment})$$

$$\text{Note: } P(\text{ a V b }) = P(a) + P(b) - P(a \wedge b)$$

Loss Risk

$$\text{pk(dp, asset, segment)} = \text{pDefenseFails(asset, dp)} * \text{pk(dp, asset, numWeaponFires(segment))}$$

$$\text{pk(threat, asset, weaponFire)} =$$

$$\begin{cases} \text{pDefenseFails(asset, weapon)} * \text{pk(weapon, asset)} & \text{If weaponFire is first of sequence} \\ \text{pDefenseFails(asset, weapon)} * \text{pk(weapon, asset)} \\ \quad * (1 - \text{pk(dp, asset, weaponFire - 1)}) \\ \quad + \text{pk(dp, asset, weaponFire - 1)} & \text{otherwise} \end{cases}$$

where

$$\text{pDefenseFails(asset, threat)} = (1 - \text{pk(asset, threat)}) * \sum_{\text{angularSegments}} (\text{min(angle / threatConeAngle,1)} * \text{pMiss(closestDefense, threat)})$$

where

$$\text{pMiss(defense, threat)} = \begin{cases} (1 - \text{pd(defense, threat)} * \text{pk(defense, threat)}) & \text{if defense is furthest} \\ (1 - \text{pd(defense, threat)} * \text{pk(defense, threat)}) * \text{pMiss(defense} + 1\text{, threat)} & \text{otherwise} \end{cases}$$

closestDefense and furthestDefense determined by lookup of range where red will shoot weapon

numWeaponFires(segment) = number of weapons threat can fire at asset over the provided segment assuming onlt that asset is within range

Mission Risk

$$\mathbf{missionRisk(CONOPs) = offenseWeight * offenseMissionRisk(CONOPs)}$$
$$\mathbf{+ defenseWeight * defenseMissionRisk(CONOPs)}$$

where

$$\mathbf{offenseWeight + defenseWeight = 1.0}$$

$$\mathbf{offenseMissionRisk(CONOPs) = \sum_{targets} (targetWeights[target] * pSurvive(target, CONOPs))}$$

where

$$\mathbf{pSurvive(target, CONOPs) = for\ blue\ asset_1 \ldots asset_k assigned\ to\ this\ target}$$
$$\mathbf{P(pSurviveAttack(target, asset_1) \wedge \ldots \wedge pSurviveAttack(target, asset_k))}$$
$$\mathbf{pSurviveAttack(target, asset) =}$$
$$\mathbf{pLossAfter(asset, attackSegment)}$$
$$\mathbf{+ (1 - pLossAfter(asset, attackSegment))}$$
$$\mathbf{* (1 - pk(asset, target))}$$

Mission Risk

$$
\begin{aligned}
\mathbf{defenseMissionRisk(CONOPs)} = \mathbf{(defensiveAssetsWeight} \\
* \sum_{\mathbf{MissionAssets}} \mathbf{(missionAssets(missionAssetWeights[missionAsset]} \\
\mathbf{*\,pLoss(missionAsset, CONOPs))} \\
+ \\
\mathbf{(defendedAssetsWeight} \\
* \sum_{\mathbf{DefendedAssets}} \mathbf{(defendedAssets(assetWeights[defendedAsset]} \\
\mathbf{*\,pLoss(defendedAsset, CONOPs))}
\end{aligned}
$$

where

$$\mathbf{defensiveAssetsWeight} + \mathbf{defendedAssetsWeight} = \mathbf{1}$$

$$\sum_{\mathbf{MissionAssets}} \mathbf{missionAssetsmissionAssetWeights[missionAsset]} = \mathbf{1}$$

$$\sum_{\mathbf{DefendedAssets}} \mathbf{defendedAssetsassetWeights[defendedAsset]} = \mathbf{1}$$